(4) Seek OHEP support for e-cloud research on HCX

Art Molvik & HCX and NDCX Groups

the Heavy-Ion Fusion Science Virtual National Laboratory (HIFS-VNL)

February 22, 2007

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Office of High Energy Physics (OHEP) support – two approaches

(A) ILC support, bolstered by being formal collaborator on CesrTA proposal

(B) Proposal to OHEP Advanced Technology R&D for halo studies

(A) Formal collaborator on CesrTA – proposed testbed for ILC-Damping Rings

- **Visited Cornell, 1/31-2/2/07 with 2 other e-cloud experts**
- **Discussed possible diagnostics for quantitative e-cloud measurements – Retarding field analyzer, grid-shielded electrode, and biased capacitively-coupled electrodes.**
- **Mark Palmer commented favorably on these suggestions during subsequent teleconference.**

Funding will require a separate proposal from me, if CesrTA proposal funded. HCX support will require additional arguments.

(B) Proposal to OHEP Advanced Technology R&D for halo studies

- **High brightness beams study group (Fall, 2006) identified halo formation as the highest priority issue: it is still not well understood or experimentally validated.**
- **Self-consistent simulation, e- & gas diagnostics, and mitigation techniques developed to an unprecedented level in our e-cloud work.**
- **These new capabilities could push halo understanding to a new level.**
- **Proposal deadline Oct. 1, 2007.**

Funding seems probable if American Competitiveness Initiative implemented; Otherwise, fighting for share of tight money.

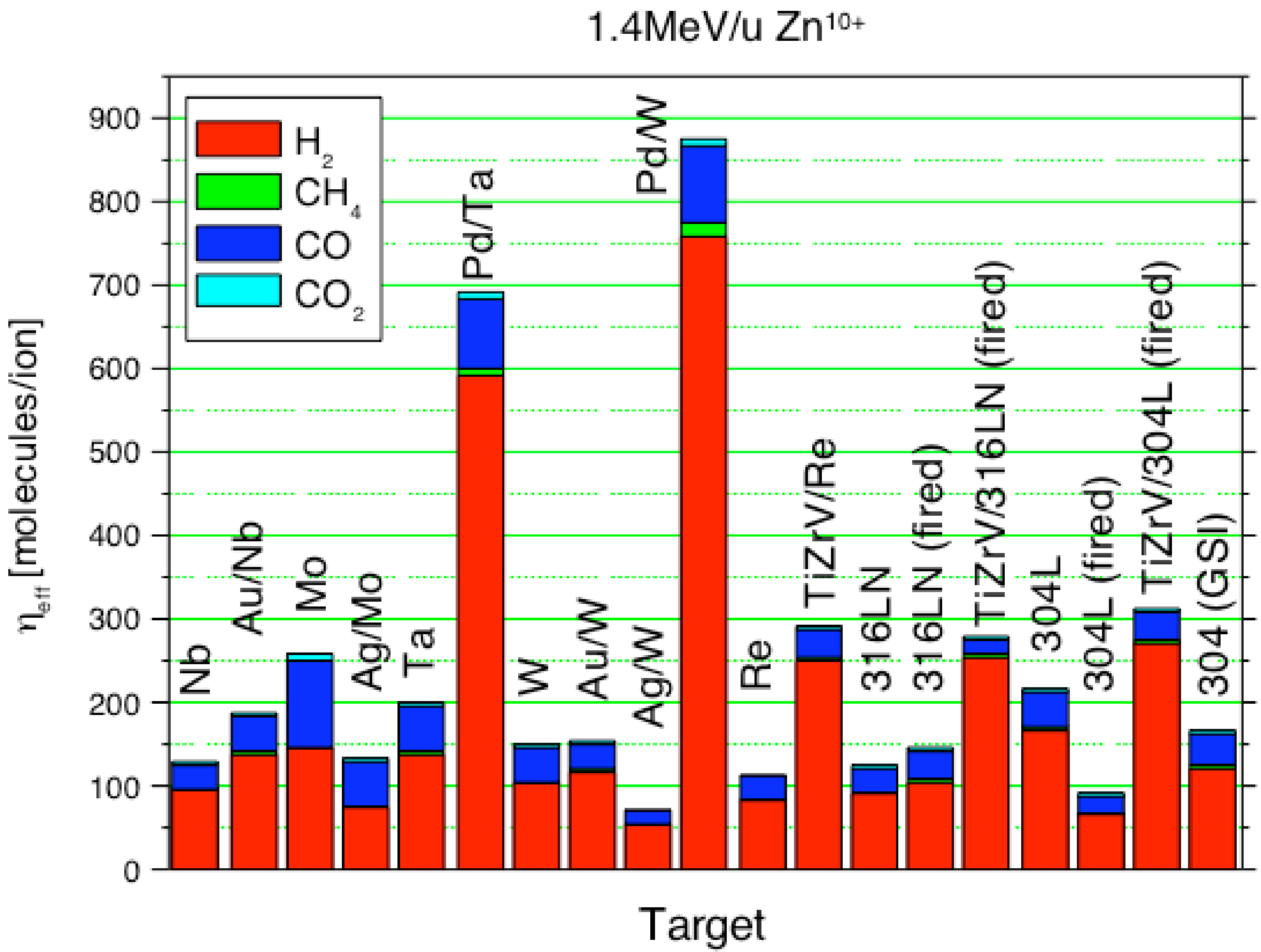
New capabilities for e-cloud & relevant to halo growth

- Reconstructed beam distributions
- Measured scaling of gas desorption coef. with ion angle & energy
- Measured & modeled scaling (ion angle & energy) of e- emission coef.
- Simulate transport of e- & gas and interactions with beam
- Multiple methods of increasing code speed by orders of magnitude – makes 3-D self-consistent simulations feasible.
- Developed diagnostics to measure details of e- & gas within beam
- Demonstrated aperturing of beam with positively bias aperture – e-emission controlled, but halo may increase:
  - Due to ion reflection, gas interaction, …?
  - Mitigations: low-oxide metal, larger diameter to scrape less, closer to knife edge to reduce scattering, run hot, …

Additional slides

- HCX aperture: clearing current grows in time
- NDCX aperture: large, constant current to EC2, very small current without aperture.
- GSI: some materials desorb much less gas than SS

Desorption varies with material



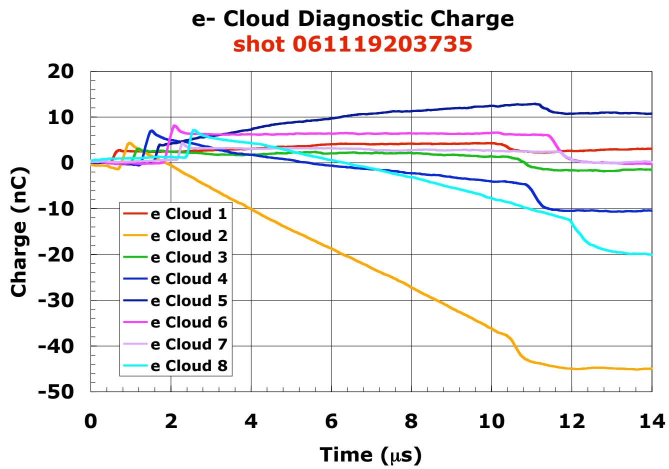
Mainly desorbed gases are H_2 and CO.

targets provided by

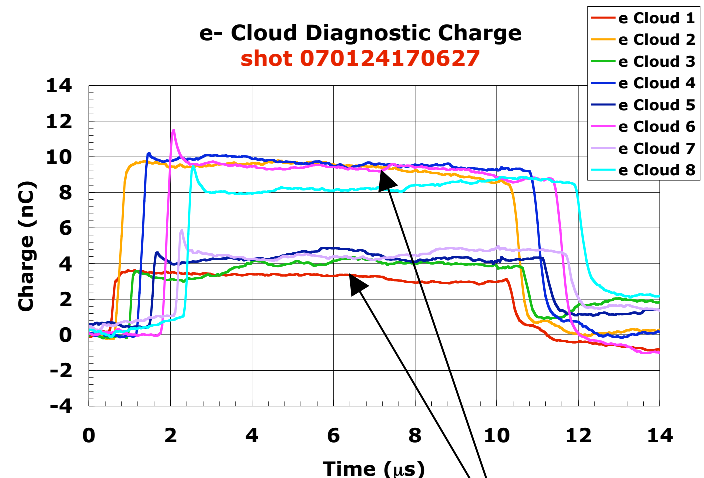
CERN

Despite E-Trap, aperture is the main source of electrons

4-STX Apertured 26-mA Beam



4-STX 43-mA Beam



	43-mA beam	26-mA beam
Diagnostic	**Charge (nC)**	**Charge (nC)**
e Cloud 1	-0.51	1.39
e Cloud 2	-1.06	-41.08
e Cloud 3	0.35	-1.70
e Cloud 4	-0.94	-11.24
e Cloud 5	-0.06	9.00
e Cloud 6	-2.22	-1.50
e Cloud 7	-0.85	-1.37
e Cloud 8	-0.35	-18.69
Total Charge (nC)	6.33	85.97

Collected capacitive charge demonstrates dependence on electrode length

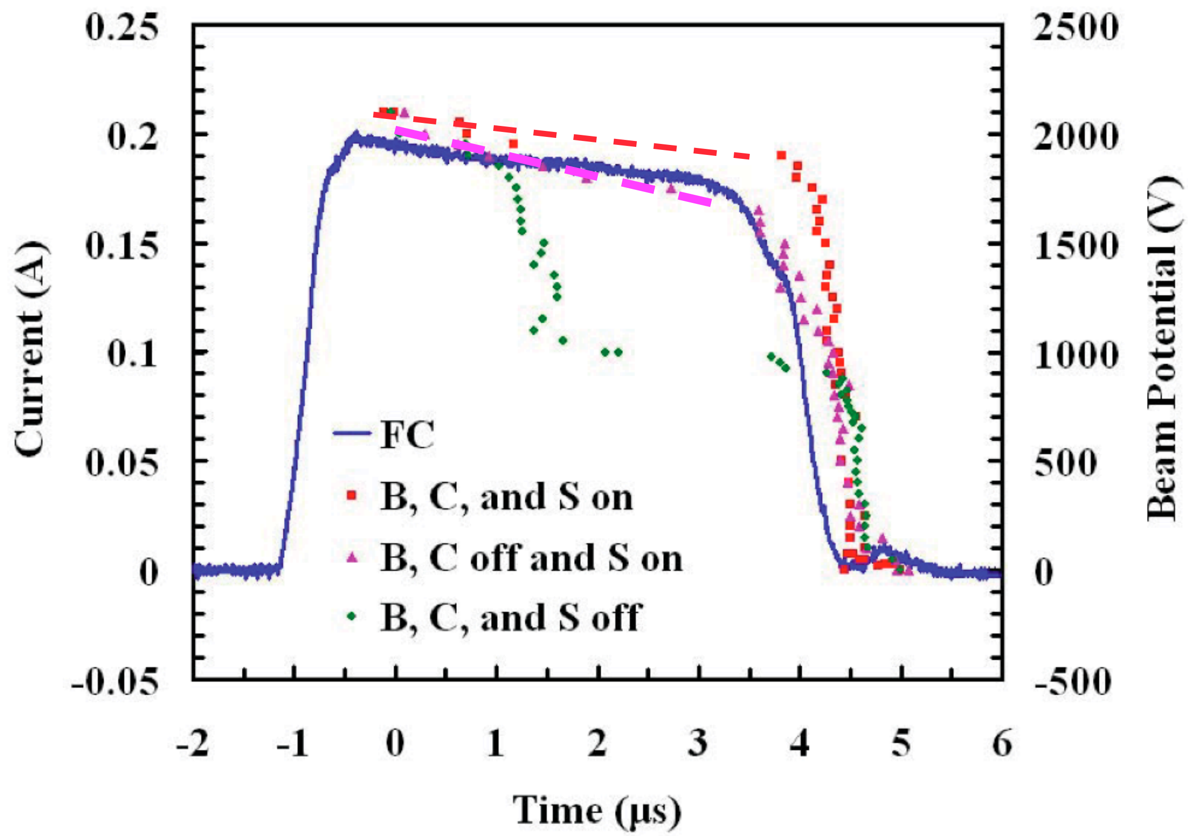
Magnetically connected to aperture – 40x current

HIFS e-cloud effort

HCX Experiment	NDCX Experiment	Simulation
Art Molvik	Peter Seidl	Jean-Luc Vay
Michel Kireeff Covo	Joshua Coleman	Bill Sharp
Frank Bieniosek	Prabir Roy	Ron Cohen
Peter Seidl	Frank Bieniosek	Alex Friedman
	Art Molvik	Dave Grote
		Steve Lund

1st measurement of absolute electron cloud density* – used retarding field analyzer (RFA) and clearing electrodes

- RFA measures max. expelled ion energy E_i (scan bias on successive pulses)
- $E_i=\phi_b$, max. beam potential
- Clearing electrode current: infer minimum n_e, and corroborate higher n_e



Absolute electron fraction can be inferred from RFA and clearing electrodes

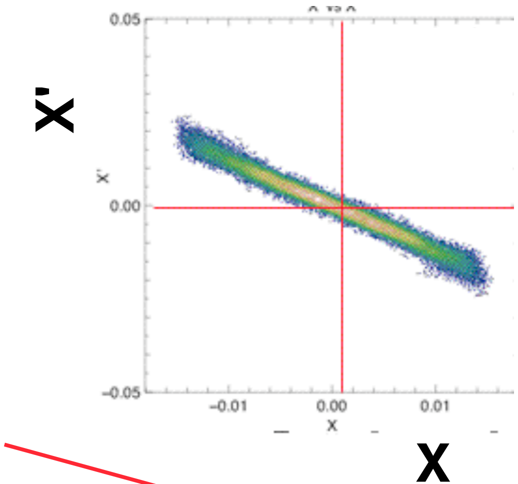
Beam neutralization	B, C, & S on	B, C, off S on	B, C, S off
Clear. Electr. A	~ 7%	~ 25%	~ 89%
RFA	(~ 7%)	~ 27%	~ 79%

*Michel Kireeff Covo, Phys. Rev. Lett. 97, 054801 (2006).

Heavy-ion beams can be degraded by electron clouds

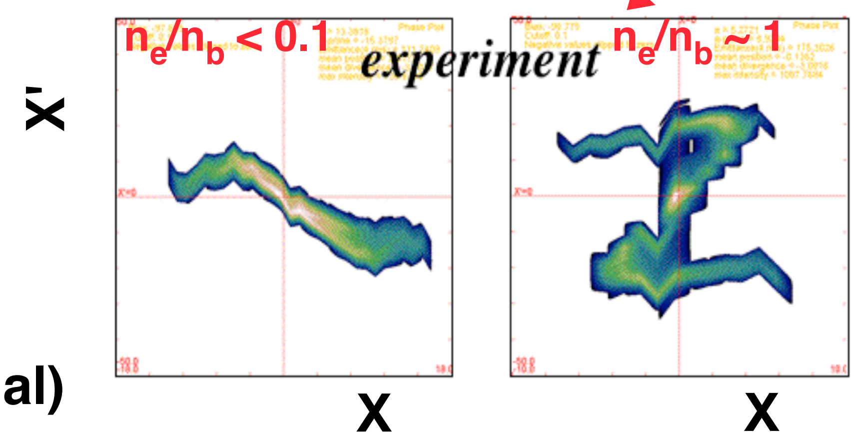
- ϕ_b depressed by electrons
- Compact phase-space essential to a small focal spot
- Ideal beam has minimum phase space

Ideal



Artificially high electron density to exaggerate electron effects

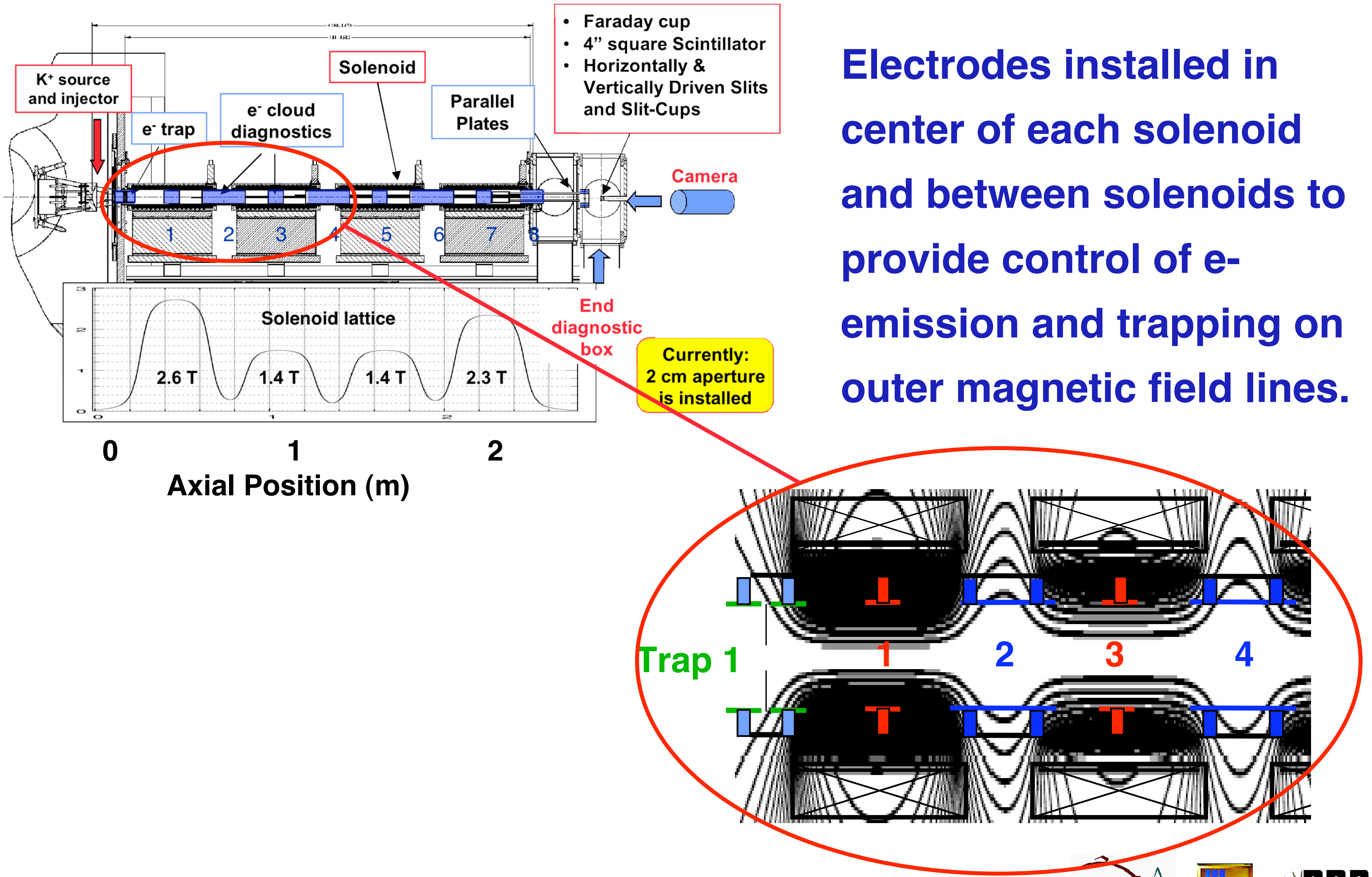
- Electrons can distort phase space, greatly increasing area of focal spot.



x = horizontal location of ion

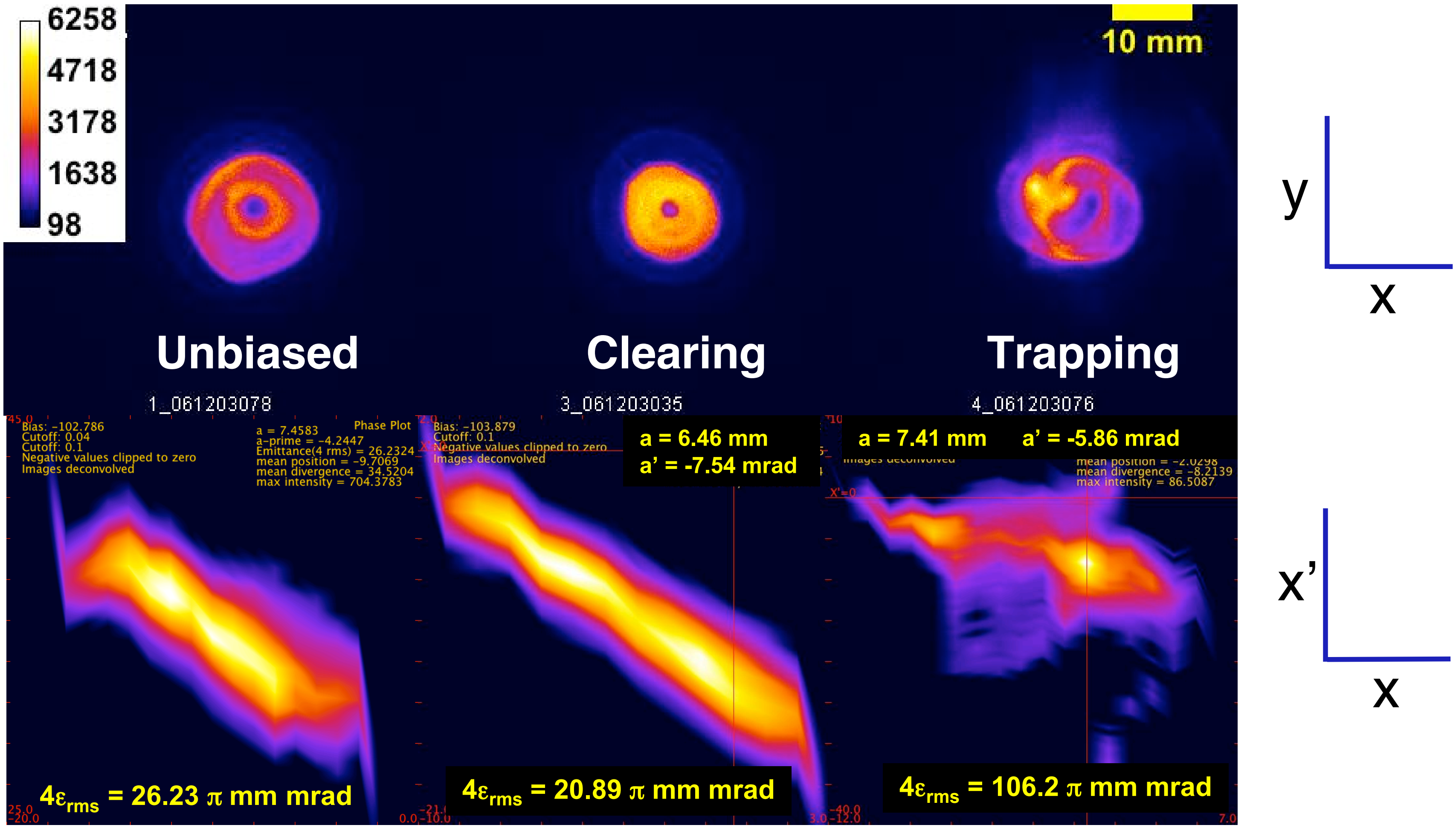
x' = dx/dz of ion (transverse/axial)

We have begun experiments studying e-clouds in solenoid magnets



Electrodes installed in center of each solenoid and between solenoids to provide control of e-emission and trapping on outer magnetic field lines.

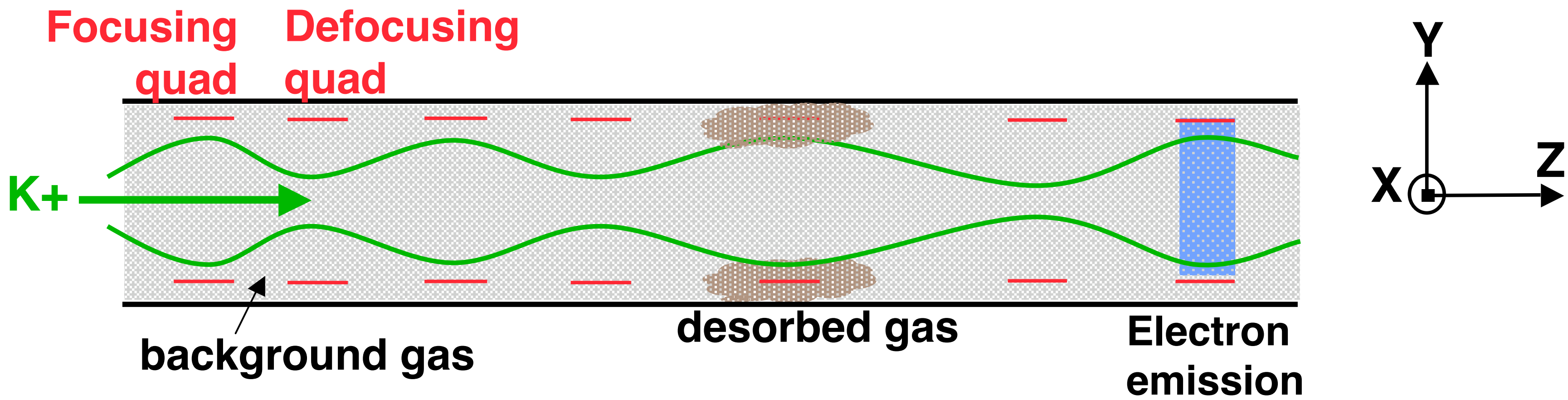
E-cloud electrode bias affects apertured beam quality



New accelerators for WDM and HIF must push performance to cost ratio, and guarantee successful operation

- Electron and gas physics likely to determine operating limits, e.g.:
  - Maximum beam current
  - Compactness - how close can beam tube approach beam?
  - Electron-ion instabilities (as seen in PSR)
- Devise mitigation techniques to increase limits
  - Clearing electrodes remove electrons
  - Roughened walls reduce electron and gas generation
  - Materials or coatings reduce electron and gas generation
  - Halo scraping by apertures reduces electron and gas generation

Control of accelerator beam-surface interactions is as important as control of MFE plasma-surface interactions

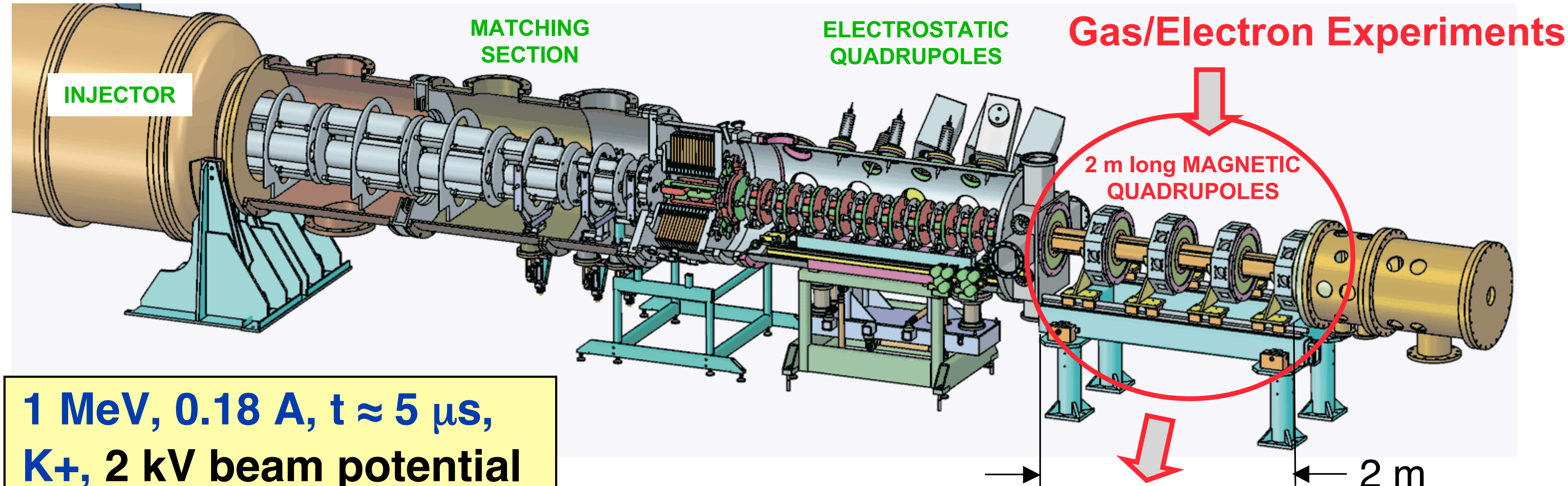


Charged particle beams transport efficiently with 'strong focusing', alternating gradient magnetic quadrupoles

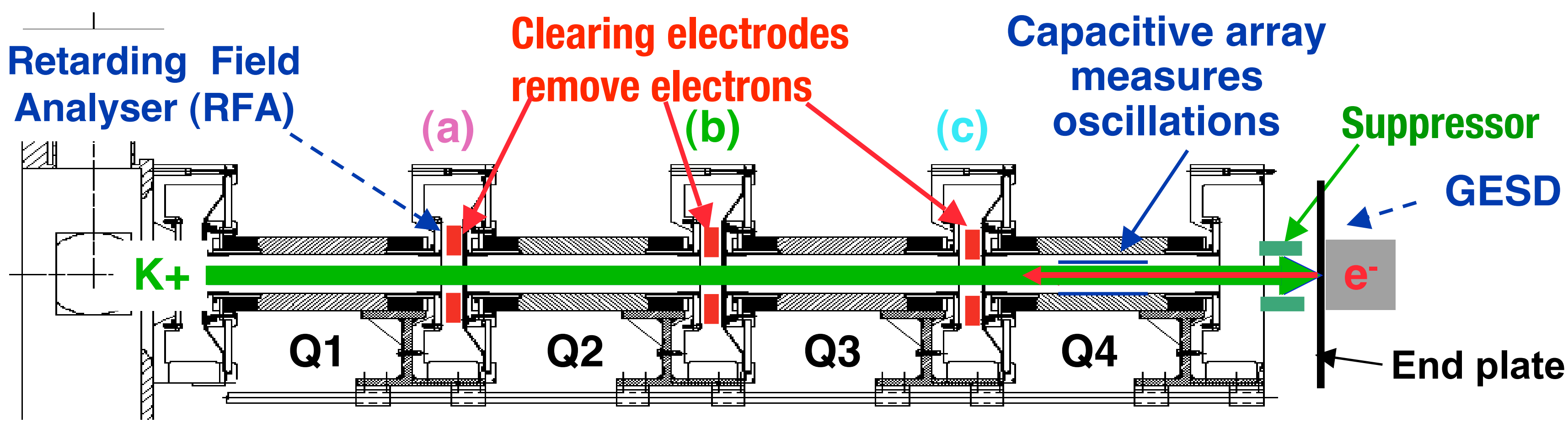
Primary:
- **Ionization of background or desorbed gas**
- **Ion-induced gas & electron emission from**
  - **expelled ions hitting vacuum wall**
  - **beam halo scraping**

Secondary:
- **secondary emission from electron-wall collisions**

The High Current Experiment (HCX) is a small, flexible heavy-ion accelerator (at LBNL)



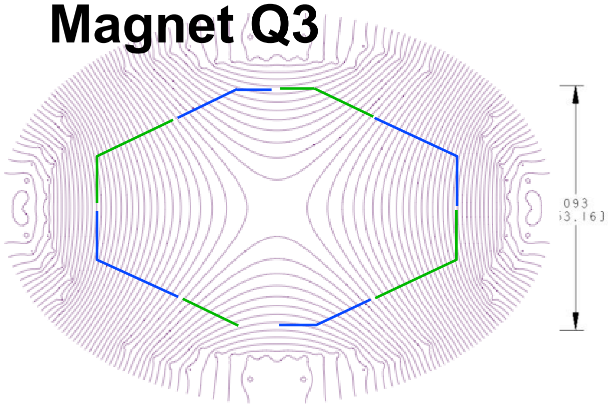
1 MeV, 0.18 A, t ≈ 5 μs,
K+, 2 kV beam potential



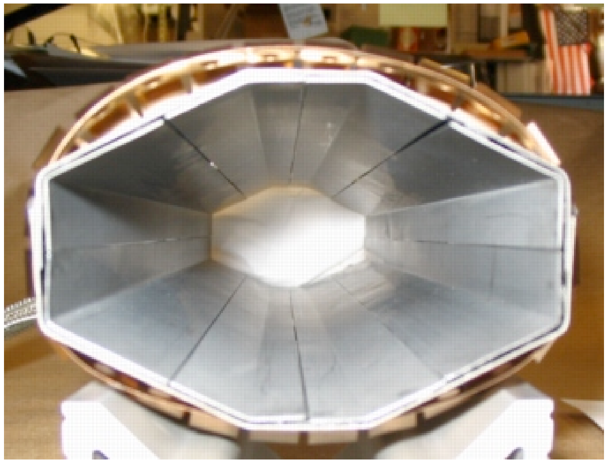
Quadrupole magnets Q1 - Q4 for beam transport

Diagnostics within magnetic quadrupole bores

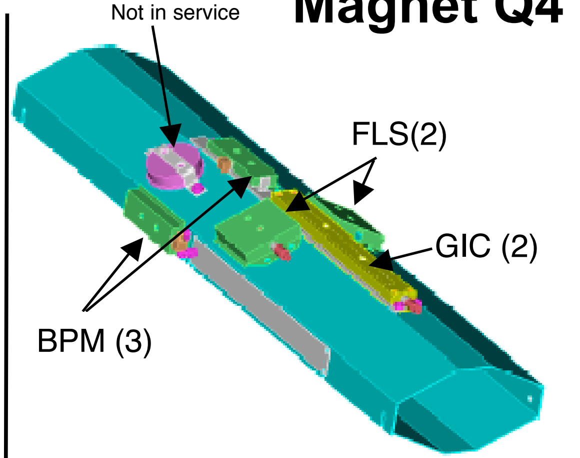
Magnet Q3

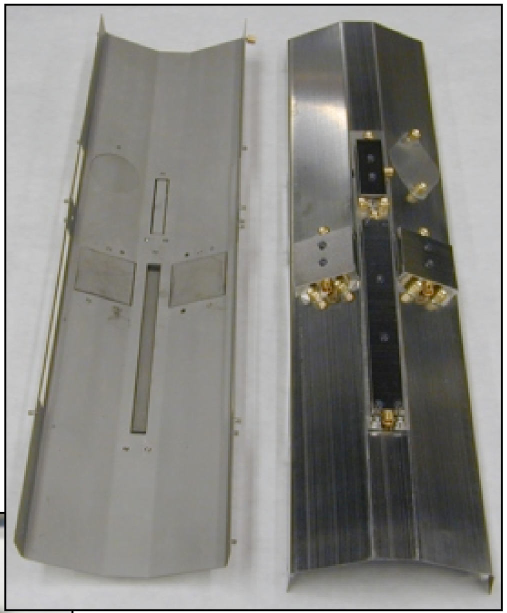


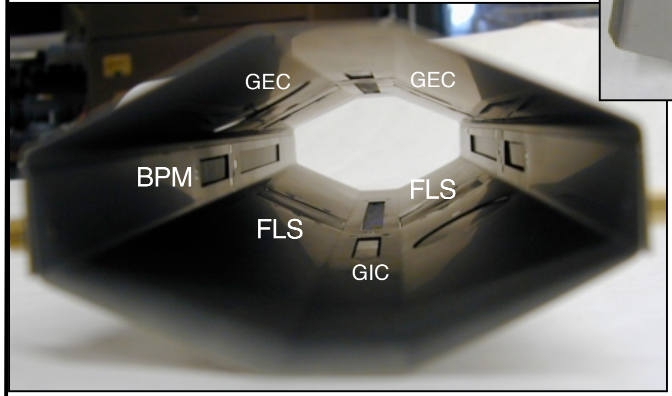
FLL: 8-biased electrodes at ends of field lines: measure capacitive signal + electrons from wall



Magnet Q4







Capacitive and grid-shielded electrodes

Outline

I. Mostly experiment

1. Introduction and experimental tools
2. Beam-surface interactions
3. Absolute measurements of gas and e-
4. Plasma oscillations

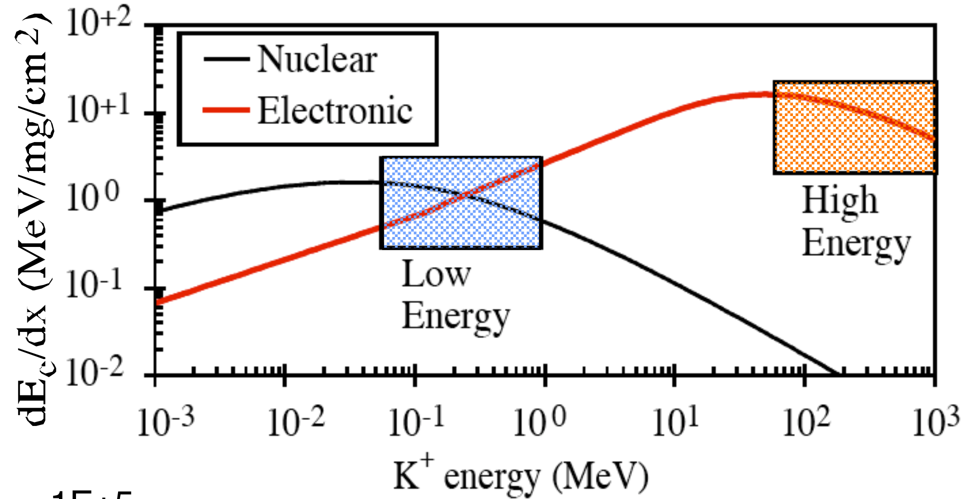
Electronic gas desorption scales with $(dE/dx)^2$, like electronic sputtering

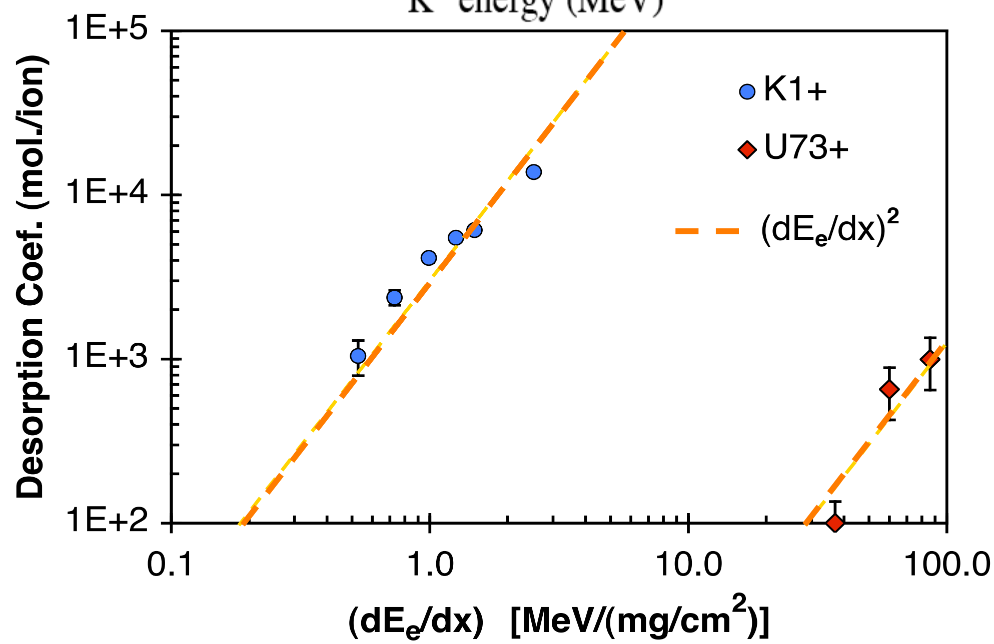
Conventional sputtering driven by large-angle nuclear scattering

Electronic sputtering more copious.

- **Well known for ions onto thick insulating layers,**
- **Scales with $(dE_e/dx)^n$ where $1 \le n \le 3$.**

Electronic desorption, $n \approx 2$.





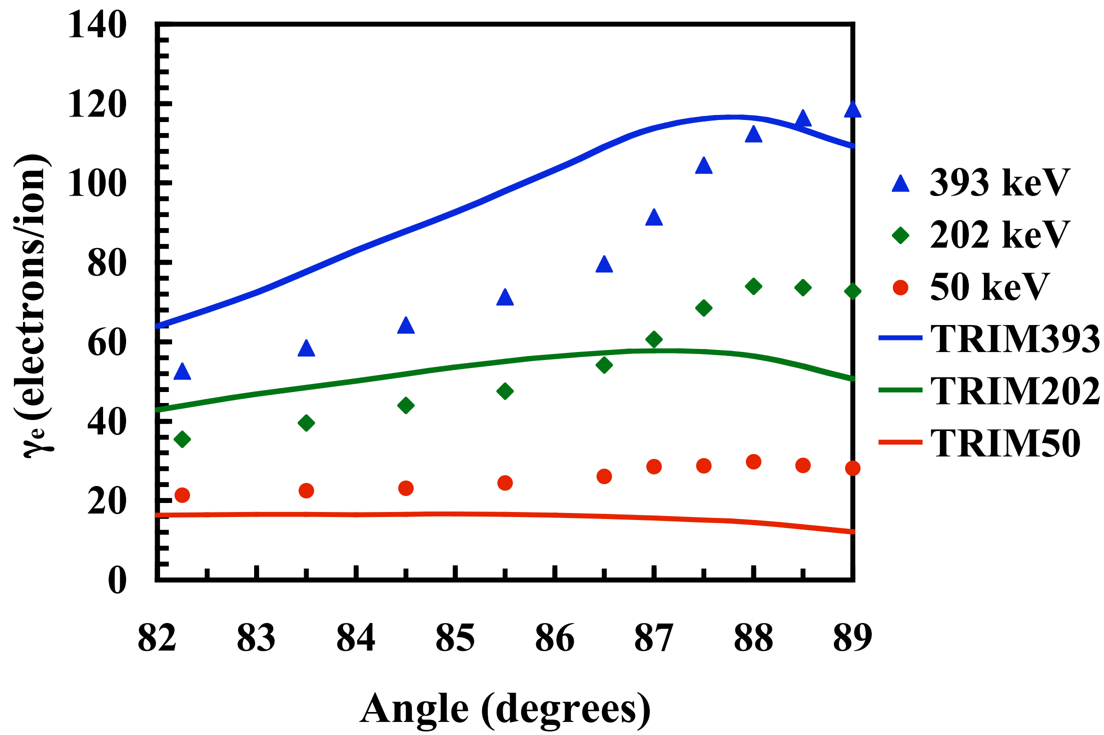
Molvik, et al., PRL ~2/9/07

Developed model for ion-induced electron yield scaling with beam energy and angle of incidence*

Model electron yield (electrons/ion) versus

- ion energy
- angle of incidence

Reasonable agreement with our measurements



Not 1/cosθ at these lower ion energies

Modified Sternglass model evaluated with TRIM code**

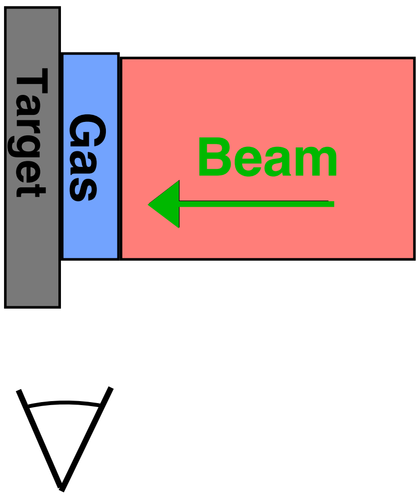
$$\gamma_e \propto \frac{\delta}{\cos(\theta)}\left(\frac{dE}{dx}\right)_e$$

* Michel Kireeff Covo, PRSTAB 9, 063201 (2006).

** E. J. Sternglass, Phys. Rev. 108, 1 (1957).

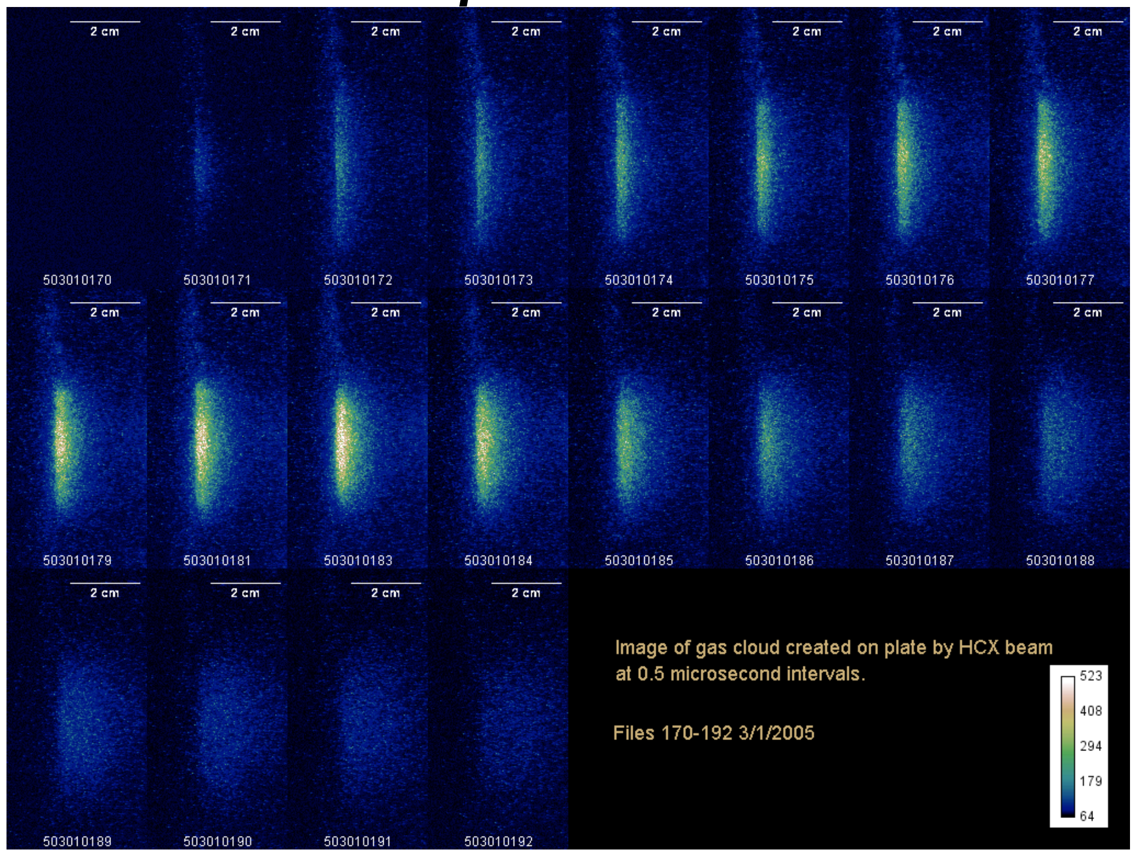
We measure velocity distribution of desorbed gas

Observation: desorbed gas in beam emits light



View expanding gas cloud from side – $f(v_0)$ normal to target [with gated camera]

0.5 μs intervals **F. Bieniosek**

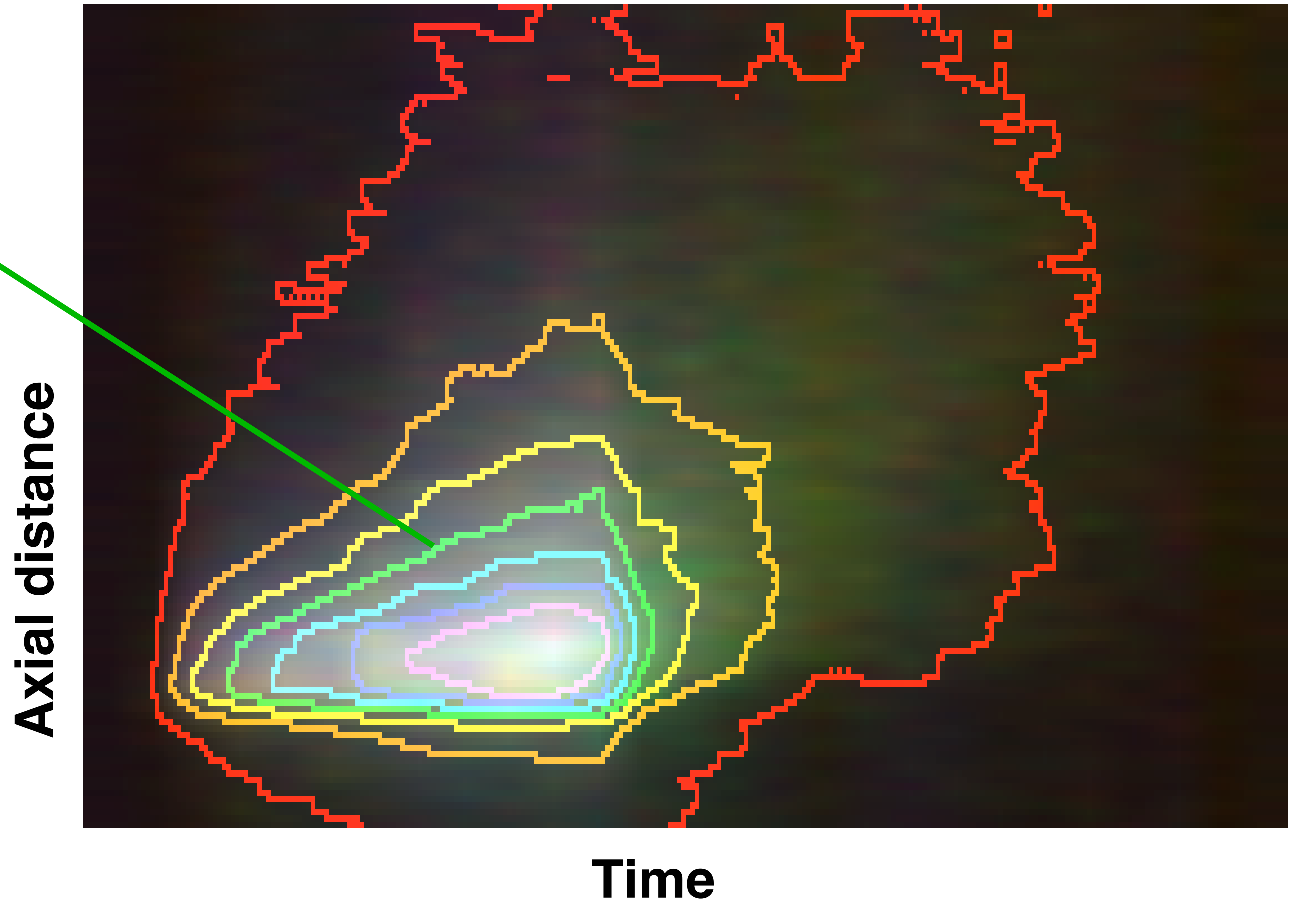


Future – absolutely calibrate camera to determine desorption yield, apply technique to non-evaporable getter (NEG)

Line integral of images indicates an expansion velocity of up to a few mm/μs

Estimated velocity:
Slope ~1 mm/μs

Corresponds to room temperature H_2, consistent with residual gas measurements



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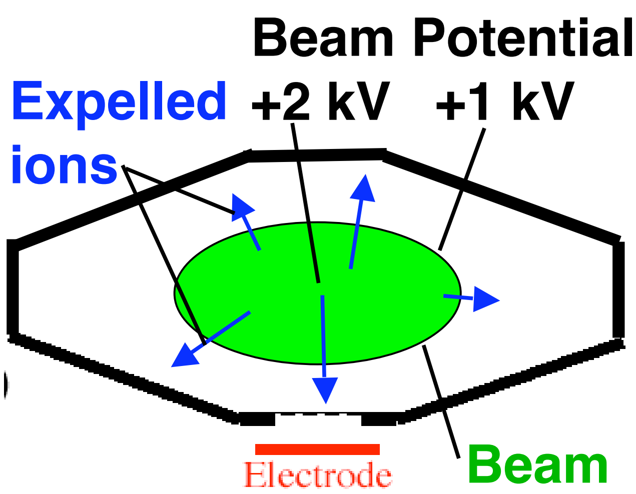
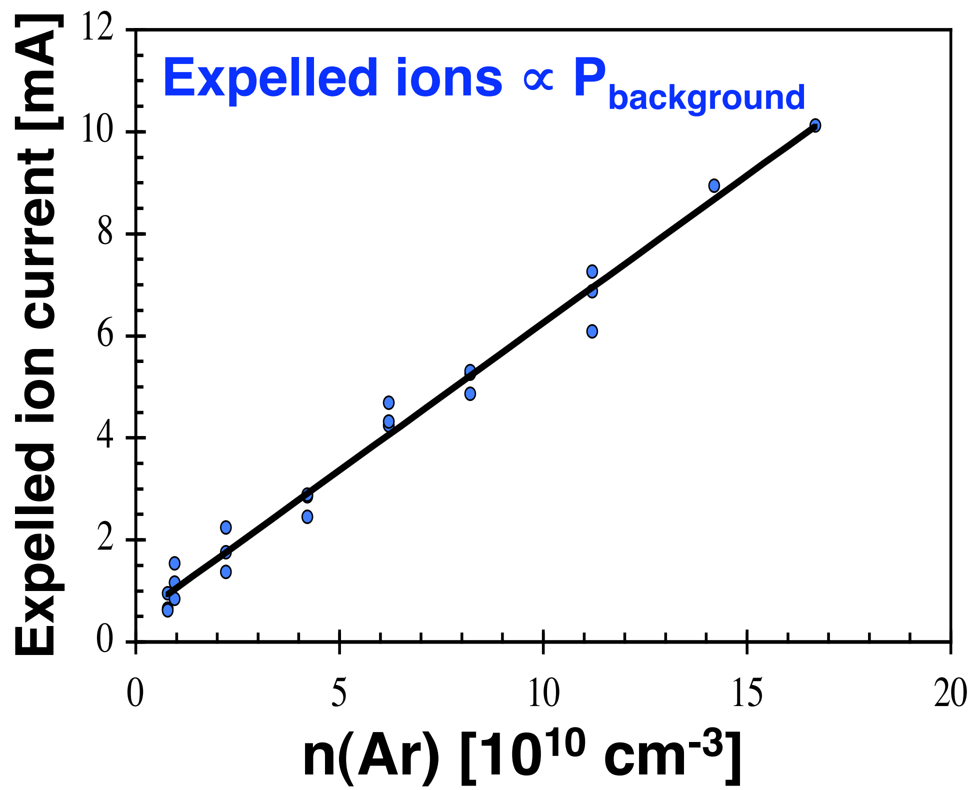
II. Mostly theory and simulation

We measure electron sources – ionization

1. Ionization of gas by beam ($n_e/n_b \leq 3\%$)



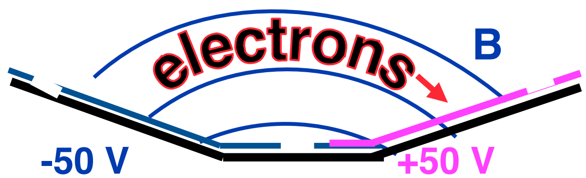


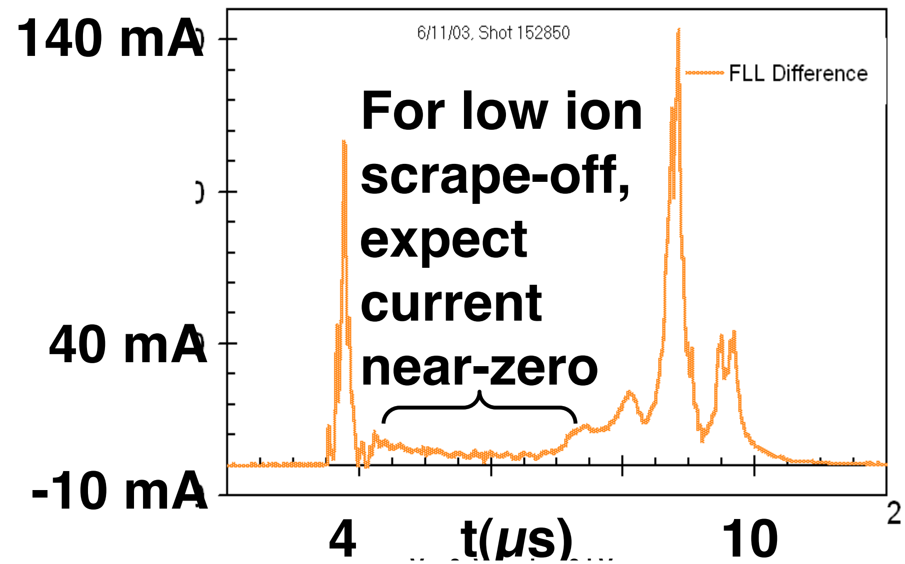
Beam current known; from expelled ion current infer

- **Ionization rate**
- **Also, gas density in beam**

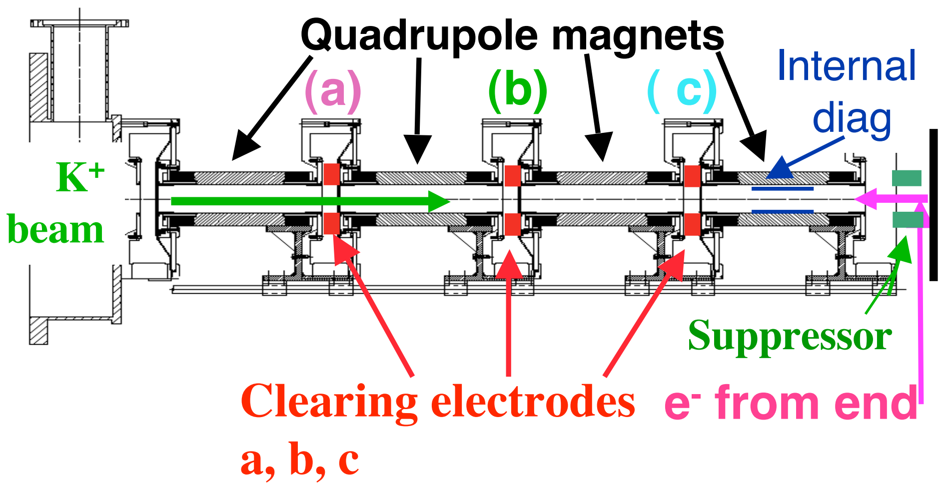
We measure electron sources – walls

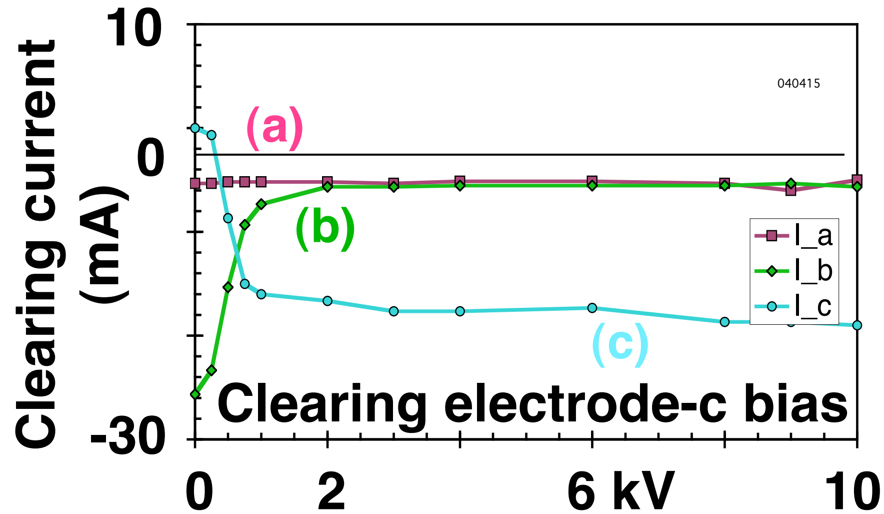
2. **Electron emission – beam tube** ($n_e/n_b \leq 7\%$)





3. **Electron emission – end wall** (n_e/n_b, 0, 100%)





Outline

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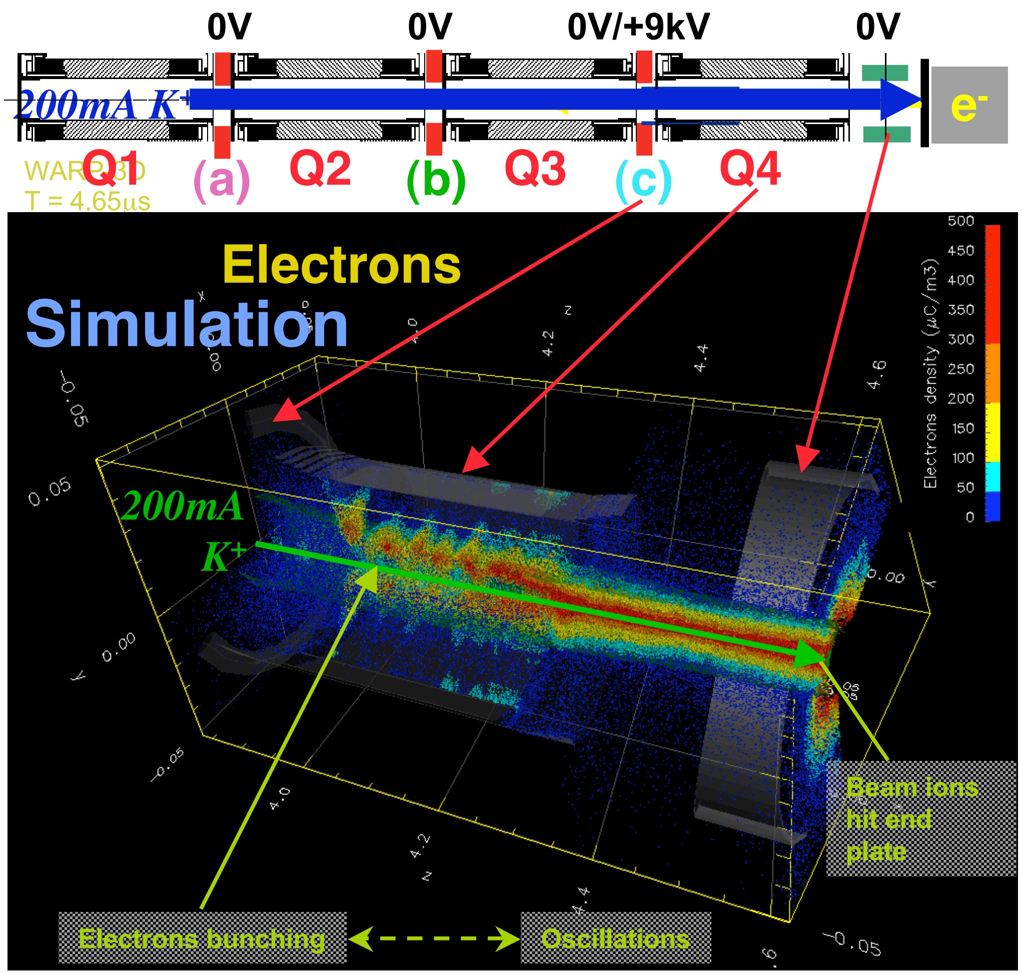
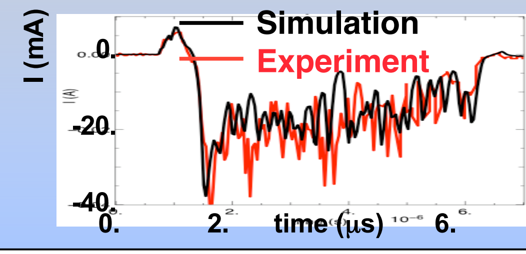
II. Mostly theory and simulation

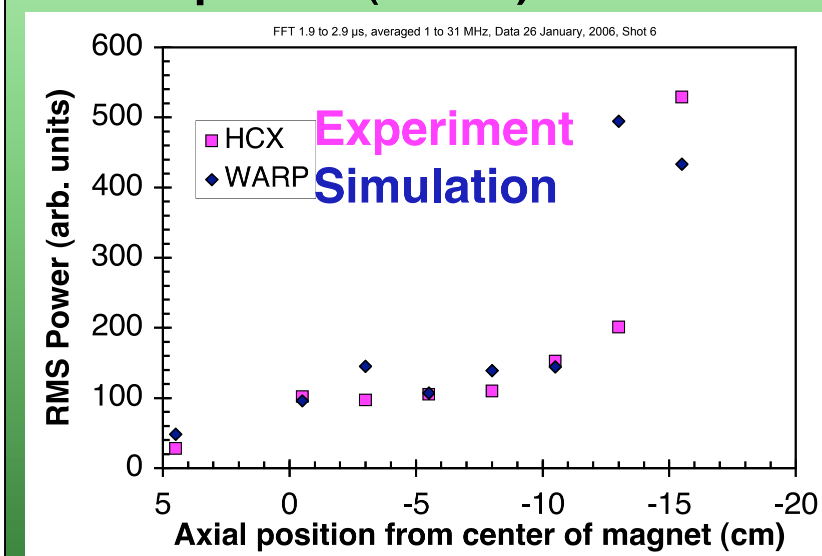
Electron oscillations – simulation & experiment agree



Current to clearing electrode (c) agrees in frequency ~ 6 MHz



Currents to capacitive electrode array agree in wavelength ~5 cm, and amplitude (below)



Summary – We have established a sound basis to understand and mitigate electrons and gas

- **Increased understanding of beam-surface interactions**
  - **Electron emission measured and modeled, $\propto dE_e/dx$**
  - **Discovered gas desorption ~ $(dE_e/dx)^2$**
- **Major electron sources measured:**
  - **Wall emission from beam-scrape-off dominates (~7%) +gas**
  - **End-wall emission suppressed to ~0% (if not suppr. ~80%)**
  - **Gas ionization small (~3%)**
- **Absolute measurement of e- accumulation as function of time**
- **Electrons bunch, generating oscillations**
  - **Simulation & experiment agree – freq., wavelength, & amplitude**
  - **Experimental validation of simulations provides credibility**